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The Introduction of New Cockpit Technology: A Human Factors Study

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ABBREVIATIONS

A/C	Aircraft
ACARS	Automated Communications Addressing and Reporting System
ADI	Attitude Director Indicator
AFDS	Autopilot Flight Director System
ALT	Altitude
APP	Approach Mode of AFDS
APU	Auxilliary Power Unit
A/T	Autothrottle
ATC	Air Traffic Control
C/B	Circuit Breaker
CDU	Control/Display Unit (Flight Management System)
CMD	Command Mode of AFDS
CRS	Course Direction
CRT	Cathode Ray Tube
CWS	Control Wheel Steering mode of AFDS
EADI	Electronic Attitude Director Indicator
EEC	Electronic Engine Control
EFIS	Electronic Flight Instrument System
EHSI	Electronic Horizontal Situation Indicator
EICAS	Engine Indication and Crew Alerting System
ELEV	Elevator
EPR	Engine Pressure Ratio
FAR	Federal Aviation Regulations
FD	Flight Director
FLCH	Flight Level Change mode of AFDS
FMC	Flight Management Computer
FMS	Flight Management System
FMST	Flight Management System Trainer
FO	First Officer
GPWS	Ground Proximity Warning System
HDG	Heading (also a mode of AFDS)
HLD	Hold
HSI	Horizontal Situation Indicator
HUD	Head Up Display
IAS	Indicated Air Speed
ILS	Instrument Landing System
INS	Inertial Navigation System
LNAV	Lateral Navigation (mode of FMS)
LOC	Localizer
MCP	Mode Control Panel
RWY	Runway
SID	Standard Instrument Departure
SPD	Speed (a mode of the AFDS)
THRTL	Throttle
TMC	Thrust Management Computer
TO	Takeoff
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation (a mode of the FMS)
VOR	VHF Omnidirectional Radio Range
V/S	Vertical Speed (also a mode of the AFDS)

SUMMARY

New cockpit technology is continually required for the airlines to remain competitive, and the manufacturers respond to this need. A historical view of the introduction of new technology suggests that the changes have not always gone as planned, and that there have been reactions to the new technology that were not anticipated. This report describes the first phase of a joint airline/NASA study which was undertaken during the introduction of a new technology aircraft, the B-767. This first phase had several objectives: to identify any adverse reactions to the new technology should any develop (none was found); to provide a "clearing house" of information for the airlines and pilots on experiences during the introductory period; to provide feedback on airline training programs for the new aircraft; and to provide field data to NASA and other researchers to help them develop principles of human interaction with automated systems.

Three airlines and their pilots agreed to participate in the study. Data were obtained through more than 100 questionnaires returned by pilots, the direct observation and interviews with pilots and check airmen, and attendance by a NASA observer at the ground schools of the participating airlines.

There are two points concerning the results that deserve particular emphasis. First, the data were taken during the early introduction of the aircraft and the conclusions apply only to that period. Second, although the B-767 was the only aircraft in the study, discussions with operators of the A310 (another new-technology-cockpit aircraft) have confirmed very similar experiences. Thus, the following conclusions, while specifically mentioning the B-767, are likely to be valid for the introductory period of the A310:

1. Most the pilots enjoy flying the B-767 more than they enjoy flying the older airplanes.

2. The pilots accept the new cockpit technology, and they choose to use it because they find it useful.

3. The pilots are aware of the possible loss of flying skill with the presence of automation, and they hand-fly (usually with flight director) to prevent this loss. The data collected in this study do not indicate any loss of skills.

4. The primary points of confusion or surprise were autothrottle/autopilot interactions; the autopilot turning the "wrong way" or not capturing the course; and achieving desired results with the Flight Management System/Control Display Unit (FMS/CDU).

5. The pilots felt training for the FMS/CDU could be improved, and they especially wanted more "hands on" experience. More training on the mode control panel, and more hand flying were also mentioned.

6. Information, especially "techniques," may not always be getting from the system designers to the line pilots.

7. Flying *any* aircraft with sophisticated equipment and high levels of automation allows distractions that cause a loss of monitoring performance.

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8. Many pilots should be trained to "turn it off" and not try to "program" their way out of an anomalous situation.

9. These field data confirm some existing human factors principles, suggest a new principle, and raise questions requiring further research.

INTRODUCTION

Background

New aircraft technology is continually required for the airlines and manufacturers to remain competitive. Most of the time the new technology takes the form of small, "add-on" systems to existing aircraft such as the Automated Communications Addressing and Reporting System (ACARS) or Ground Proximity Warning System (GPWS). Infrequently, there is a dramatic change in cockpit technology, as with the introduction of the B-767 and Airbus A310.

The Operators' View

Based on previous experience with new technology, it was expected that there would be con comitant changes required in the role of the crew, piloting techniques, procedures, and training. It was generally perceived that previous conversions to new technology did not always go smoothly; that many airlines experienced higher-than-expected training costs; and that some pilots had experienced difficulty in the transition to the newer wide-body jets (the L-1011 and DC-10). There have been several explanations offered for this: certainly, the flight guidance systems on these aircraft are more complex than those of their predecessors, but it has also been noted that the captains transitioning to these aircraft had not been to school in periods of 10 to 15 yr, and this may have contributed to some of the difficulties.

As new technology in any field is developed, there are some events that were seemingly not anticipated by the designers. The GPWS, although admittedly introduced into service before many felt it was ready, has caused pilots to turn it off because of the high false-alarm rate of the system (Wiener and Curry, 1980). Subsequent changes in the alarm logic and display logic have modified this this situation substantially. The Inertial Navigation System (INS) provides another example. It is true that, as automatic navigators, they navigate more accurately and more economically than manual navigators, but the class of navigation errors has changed so that a measurable fraction of errors occur due to the insertion of incorrect data and/or movement of the aircraft while the INS is aligning itself. Both types of incidents have caused aircraft to takeoff only to have to return to the airport because of these inappropriate actions.

A third example of an unanticipated side effect of automation has been observed by the airlines when pilots transitioned from first-officer on a wide body aircraft, with significant levels of automation, to upgrade to captain on a narrow-body aircraft, with less automation (Wiener and Curry, 1980). At first, there was a higher than expected failure rate, but this has diminished after pilots started preparing themselves before the transition by performing more manual flying on the wide body aircraft. Many pilots have heard of others' experience in this area and have altered their own use of the autopilot to avoid the apparent loss of skills.

The Human Factors View

In many respects the technology of human factors has not kept pace with the technology of the cockpit. There is a significant body of knowledge on how to design displays and controls – material on which manual systems are based – but there is little material to help the human-factors practitioner with the design of interfaces to complex devices. It has been felt by many observers that the performance of such systems will be determined less by traditional manual piloting skills, but more by the pilots' decision making behavior (what mode should I use?); their knowledge of the systems (is this thing working correctly?); their monitoring behavior (keystrokes entered now may influence the system 5 hr later); and crew coordination (setup and monitoring of the systems and other members of the crew).

The job of the systems designer and operator is made even more complicated since many outcomes of the design and operation (such as the loss of skills described earlier) do not emerge until a considerable amount of experience with the new equipment has been gained. This is precisely the type of information that cannot be obtained in simulation, the traditional design tool.

In short, new human-factors techniques are required to assist in the design of new cockpit technology.

Study Objectives

The objectives of the joint airline/NASA study were as follows:

1. To identify any unanticipated side effects of the new technology.
2. To provide feedback to the carriers on their training related to the new cockpit technology.
3. To help the exchange of operational experience among carriers.
4. To provide quantitative data on the human-factors aspects of the new technology.
5. To provide field study information for later development of human-factors "principles" of automation.

DESCRIPTION OF THE STUDY

The study was conducted with the help and cooperation of hundreds of other individuals within the three participating airlines. The major sources of information used in the study are outlined in this section.

Ground School

The NASA observer attended the full (2 wk) ground school of one airline, and 1 week periods at each ground school of the other two airlines; these periods coincided with instruction of Flight Guidance, instrumentation, and the Flight Management System. The observer did not take the oral exam or any simulator training, but he did observe three 4-hr simulator training sessions.

Pilot Volunteers

Pilot volunteers from the three participating airlines were solicited from those who attended 767 transition training. A procedure was established with the carriers whereby the anonymity of each pilot would be preserved by having him adopt an identity code number. This was necessary to establish identification for a possible second round of questionnaires. Invitations to participate in the study, including a five-page question-and-answer booklet, were prepared for each airline. Initially the invitations to participate were distributed when the pilots enrolled in the ground school for transition training. Later this was changed so that the pilots received material after their simulator training, either before or just after their initial operating experience.

Questionnaire

The primary data-collection device was the questionnaire (see appendix A). Over 100 returns were received and 102 were used for most of the analyses. The questionnaire consisted of three parts:

Frequency-of-Use Table

This part was designed to to determine what features were being used by the pilots, and how frequently they used these features.

Open-Ended Questions

The open-ended questions were designed to obtain information on confusing aspects of the systems; the features and systems that the pilots like and find useful; characteristics that they don't like; the aspects of the cockpit they would change if they could; and their opinion about the training they received.

Attitude Survey

This portion of the questionnaire consisted of 36 statements about the pilots' opinions on automation and flying in general, and the airplane in particular; the pilots responded on a five point "agree--disagree" Likert Scale.

Interviews and Meetings

Informal interviews were held with approximately 20 pilots and 8 check pilots. Each interview lasted from0.5 to 1.5 hr. hours.

Progress report meetings were held at each of the three participating airlines. Attendees of these meetings consisted of representatives from flight operations management, training, line pilots, and check airmen. These progress reports seemed to have a catalytic effect, since they always evolved into a spirited discussions [illegible]g all attendees.

Cockpit Observation

The NASA observer flew as cockpit observer on one training flight (two pilots received training on this flight), two segments during which a captain was receiving line training, and approximately 40 segments with line pilots operating the aircraft in normal line operation.

Internal Documentation

The airlines made available any pilot reports of irregularities or incidents that occurred.

RESULTS

Questionnaires

Respondents

A total of 104 questionnaires had been received between February 22, 1983 and July 31, 1983 (the cutoff date for the analysis). Two of the questionnaires could not be identified with a specific airline, so they have not been included in the analysis. The distribution of responses by airline, position (captain/first officer), total flying time, and time in the 767 is shown in Table 1. An interesting fact is that a majority of the respondents were captains, whereas our past experience has been that first officers are usually more likely to participate in studies of this type.

Frequency-of-Use Table

The frequency-of-use table was distributed in two forms (see Appendix A) because of some ambiguities in the instructions and some apparent inconsistencies in the responses. These inconsistencies make it difficult to draw conclusions from these data alone, but these data are useful for confirming results suggested by other sources. See Appendix B for details.

Open-ended Questions

Without a doubt, the answers to the open-ended questions were the most difficult to extract and summarize, but they yielded extremely useful information. Included in this category of responses were any notations from the comment column of the frequency-of-use table, or comments from the pilot opinion portion of the questionnaire. These additional comments were solicited, and were quite useful.

After approximately 30 or so questionnaires were carefully examined, several categories of response began to emerge. The responses to the open-ended questions are shown in Table 2, and have been grouped into Features Liked, Features Missing or Not Liked, Points of Confusion or Surprise, and Training. Not included in these responses are those comments relating to human engineering and cockpit environment issues, or comments regarding the implementation of a particular feature if they were not pertinent to the present study.

The narrative responses below are complete. They are brief because an essay response was not requested, nor was space provided. Nonetheless, they do convey the pertinent information.

Features Liked The pilots felt positively toward the Autopilot Flight Director System (AFDS) and Autothrottle (A/T) System. When asked what feature they liked about the AFDS and autothrottle system, the pilots' responses involved the general concept of autothrottle and speed control

"A/T, saves fooling around setting power"

"speed control without constant monitoring"

"reliability and flexibility (i.e., variety of ways of achieving an objective" "automatic changeover to .80 mach from 300 knots and vice versa"

"throttles very handy in terminal area"

"all"

They also liked the AFDS and Thrust Management System during takeoff when the possibility of overboosting the engines is negated by the Electric Engine Control (EEC). Also mentioned were the reduced workload, altitude-capture, and altitude-select features:

"like TO power feature"

"TO and climb"

"with EEC the ability to keep engine at proper N1 without having to set power manually"

"autothrottle overpower protection"

"altitude capture at preset speed on descent"

"reduced workload; correct power is set"

"saves time and effort setting different thrusts"

"enables the pilot to narrow attention pattern when necessary to concentrate on most important objectives"

"ease of operation with reduction in workload

The Electronic Flight Instrument System (EFIS), or Attitude Director Indicator (ADI) and Horizontal Situation Indicator (HSI) Cathode Ray Tube (CRT) displays received enthusiastic response. Most of the comments were general in nature, and referred to the information on the displays and the clarity of the displays

"I can't describe it, but there is something visually pleasing about the CRT presented instruments and Flight Director"

"Easy to read, and all info readily available"

"Very bright--always know where you are"

"Good display--easy to read, and a wealth of information"

Specific mention was often made of the map display

"The map mode and the HSI is a wonderful tool" "multitude of capabilities"

"works well, useful"

"total amount of information is great"

"ability to burn my map!"

In addition, two pilots specifically pointed out the advantage of having the route displayed on the CRT map dislay, a combination of the EFIS and FMS capabilities.

"being able to string out the route with few entries"

"ability to build a map presentation"

EICAS The Engine Indicating and Crew Alerting System also received many favorable, if general, comments about the quality and quantity of information on the display.

"good, easily scanned displays, readily seen from any seat/cockpit position; excellent alerting system"

"warning and annunciation of practically everything"

"immediate info on status of airplane"

"clarity of and ease of reading the displays"

"much attention in small space; warning system gets attention"

"quick glance comprehension of A/C system status"

Specifically mentioned by several pilots were the explicit display of eng limits as well as the ability to monitor a large number of variables.

"anti-ice & exceedence displays and TMC [thrust management computer] combination"

"limit displays"

"all engine limits well displayed; no numbers to remember"

"monitoring capability"

"cautions and warnings"

"annunciations for prompt attention"

"...engine displays and controls"

"constant monitoring of systems"

"alerts crew to any malfunction, and [I] like the call system (red, yellow)"

"the needle style of display catches the eye when something changes [compared to] digits"

"color changes with warning/caution'

Features Not Liked or Missing There were not many features relating to the present study that the pilots either did not like or felt were missing. An almost traditional complaint of computer users is the slow response time, and these pilots were no exception. Usually, the complaint concerned their time in the terminal area where they perceived fast flight crew response as a necessity due to ATC changes:

"sometimes slow to accept information and update display"

"they didn't make it sophisticated enough—it is too slow"

"sometimes takes too long to bring up system and execute it"

"difficulty and length of time to reprogram approach once it is activated"

"seems a bit cumbersome at times--making changes for approach (as controllers are prone to do)"

"dislike being unable to change approaches quickly; need a way to clear out old approach in one step, so that new one can be inserted quickly"

Pilots from airlines that did not use mechanical checklists felt they would be useful, and many thought a checklist should be on the EICAS.

"checklists, emergency and irregular procedures should appear in conjunction with key events (e.g., gear-down, engine failure, etc.)"

"checklist on control column plate holder"

Others felt that the the circuit breakers and spare light bulbs should be within reach of the pilots; even though the design philosophy precludes the necessity of needing these, the exigencies of line operation made the pilots think otherwise

"have spare bulb box within reach when seated" "place circuit breakers in place where one pilot didn't have to get out of his seat to reset"

"the most important [cockpit change] is to bring all controls, spare bulbs, C/Bs, etc. to within reach of pilots ... very important for two man crew"

"move the spare bulbs where I can get to them. Way in back is no good on final with a blank gear down indicator"

"We had both lights in the right main gear out on final approach and had to go around while the FO got out of his seat and found bulbs in the dark. Move spare bulb supply or have a second supply."

Points of Confusion or Surprise The first three General Questions yielded most of the responses relating to points of confusion or surprise, especially question number 2. Only the more significant categories will be described here.

Autothrottle-V/S-SPD Interaction A significant number of pilots reported confusion on the interaction of pitch autopilot and autothrottles.

"seems easy to turn off autothrottle intentionally and then get it back by getting into a speed mode and not realizing it at once"

"sometimes autothrottles reconnect when not expected to, even though they are working normally"

"occasional misunderstanding of FLCH capability with [autothrottle] turned off"

"cannot always obtain zero thrust; why?"

"some confusion as to when A/T will reengage after manual disconnect"

"trying to lose altitude with speed brakes, and then throttles power up the engines"

"once aircraft leveled at uncalled for altitude, and autothrottle did not respond"

"[have observed] confusion between SPD on A/T and SPD on pitch, and many similar problems"

"descending in CMD, V/S, throttles at idle, autothrottles disconnected but armed. [Mode control panel] airspeed is well below existing speed. When I select SPD the autothrottles come out of idle. As far as I am concerned, this is not logical. Result: I disconnect A/T."

"interface between V/S and SPD is bad—won't let throttles come back to idle and then [throttles are too] slow to react."

"Autothrottle is difficult to use properly, particularly in use with descents. When manual throttles are used, they stay wherever you put them. With A/T, it is necessary to constantly check power which actually increases workload."

Speed Sync at FLCH Engagement A seemingly related comment is the speed synchronization at the time Flight Level Change (FLCH) is engaged. Regardless of the value displayed in the speed-select window at the time FLCH is engaged, this displayed value is changed to the existing speed and the pitch autopilot holds the existing IAS. The autothrottles advance to maximum allowable thrust (if climbing) or reduced thrust (if descending). Most pilots who reported this confusion felt the target speed should have been that which was displayed in the window at the time of engagement.

Aircraft Turns "Wrong Way" or Does Not Capture Pilots reported that while on autopilot the aircraft turns the wrong way, especially upon localizer intercept or after crossing a waypoint, or that the LNAV system did not engage at all.

> "twice approaching XXX Rwy ILS12; once the aircraft leveled at uncalled for altitude, and autothrottle did not respond; second time, aircraft began non-specified climbing right turn after tracking in "APP" mode on ILS (autothrottle was inop)."
>
> "hard pitch down in terminal area could not be explained."
>
> "autothrottle (1) took off at flare; (2) started [go-around] at 400' on approach"
>
> "approach to YYY ILS22R: aircraft turned about 40 degrees right of approach course just prior to [outer marker]...no apparent reason for malfunction."
>
> "...the autothrottles occasionally don't engage during TO and climb; the automatics occasionally don't properly lock on during localizer capture."
>
> "when using the direct/intercept, a number of pilots, including myself, have forgotten that the active waypoint must be ahead, not behind. Aircraft will not intercept desired course. In similar situation, aircraft will turn back to active waypoint behind, (if you let it). This has 'surprised' several of us."
>
> "We were cleared direct ZZZ. We used the fix key to define all of the abeam way points. We activated the route. Subsequently, we were given an off course vector for traffic. When we were again cleared on course, we did not pass within 2.5 miles of WWW, so the aircraft started to go back to WWW."
>
> "Enroute New York over TTT, [the FMS] suddenly drew a perfect 360 degree circle and immediately started to turn."
>
> "twice when in approach mode at YYY, the autopilot tuned to intercept localizer when 5 miles or more to go. When reset on approach mode actually approaching localizer, flew through completely."
>
> "Have seen A/P 'capture' an ILS while still at least 5 miles away. Have also seen A/C start to turn the wrong way to capture a radial."
>
> "Twice the heading select, when activated, has begun a turn in the wrong direction."
>
> "Locked onto LOC, followed by disengage and turn away from LOC course."

"Had the aircraft start a turn at a waypoint when it should not have while in LNAV. Probably was an old route still in CDU that was not properly erased."

"In LNAV, airplane started out on excursion for no known reason--it happened twice, both at waypoints."

"Unexplained turns away from the LNAV course magenta line. Also no capture of certain departure SIDs although they were adequately displayed."

An obvious drawback of voluntary reports such as this is that it is not always possible to isolate the cause of these events, e.g., system setup error, system malfunction, or incorrect knowledge of the system itself. The same situation exists with the reports about unselected mode changes. The following reports are typical:

"had MCP switch from FLCH to V/S 3 times."

"the system has switched from FLCH to vert spd. twice."

It is likely that the events happened as reported, but it it is also difficult to isolate causes from such brief reports.

Heading Display on Track Up Map Eleven pilots reported confusion between the heading orientation and the track up nature of the map display; as they describe it, this almost always occurs during vectoring in the terminal area when they are controlling aircraft heading, not track.

"Flying a HDG, when initially checking out on A/C when in map mode."

"Heading info is hard to get used to. All of us have trouble finding heading info."

"'Track up' presentation disconcerting when trying to maintain heading manually."

"Pilots fly using heading, engineers use track. Heading should be prominently displayed at top of map."

Training

Four of the pilots felt their training was adequate and did not require any changes.

FMS/CDU The great majority, however, had at least a few comments to make, especially regarding the FMS/CDU and the type of training desired.

"[more] use of CDU, i.e., 'rules' of CDU--what it will and won't do, using all the different ways to get a job done"

"[more] CDU. CDU. CDU...the simulator wasted incredible time because no decent CDU training device [was available]."

"more emphasis on FMC; need FMC trainer" "without a doubt, the FMS and CDU should receive much more emphasis."

"More practice and hands on a fully operational 'identical' FMS/CDU and practice to full proficiency."

"...Insight into the capabilities of the [FMS/CDU] systems would be better obtained through an actual data-based trainer that operated in real time and allowed trial and error: Inputs/Mistakes/Corrections/Learning!"

Related comments referred to the specific exercises that they felt would be useful:

"[more] CDU use in simulator with emphasis on everyday line use combined with typical line ATC clearances."

"A little less FMC--or a more practical approach."

"Less emphasis on VNAV (since it's not installed), more emphasis on CDU programming."

AFDS Training Several of the pilots would have liked more training with the AFDS and Mode Control Panel.

"The simulator should establish basic flying skills with the AFDS prior to using the automatics."

"[more] operation of all automatics. A hands-on mockup is needed in ground school."

"[more] autoflite system. If procedures for use were drilled slowly in a step by step fashion, particularly during TO profile and approaches, if these procedures were down cold before simulator training, simulator would be much easier."

"[An] absolute necessity [is] basic AFDS training! Why do we have this autopilot? What is it trying to do? What is the design philosophy? Needed after this: DRILL! DRILL! DRILL! with no other simulator movement, just AFDS...."

"More line oriented crew duties (log book, set up, comm, etc.)"

Additional Flying A significant number of pilots wished to have more experience hand flying the simulator, and several suggested the order of presentation of the material.

"Hand flying needs more emphasis. Total time should be increased. Co-pilots should get equal time."

"More manual flying. This airplane will fly just fine without the AFDS and autothrottles."

Pilot Opinion Questionnaire

The pilots responded to 36 statements and were asked to circle one of five answers to describe how they felt about the statement: strongly agree; slightly agree; neither agree nor disagree; slightly disagree; or strongly disagree. Their responses were examined to determine if there was any correlation with the following variables: airline, total flying time, flying time in the 767, and their position (e.g., captain or first officer). In addition, a factor analysis was performed to determine if there were any underlying dimensions to the response to the 36 questions.

All responses were pooled and the results appear in Table 3 for each of the 36 questions.

Airline Differences A contingency table analysis was first performed to determine whether or not any gross differences existed between airlines. The responses were pooled into a 3 X 3 matrix consisting of the three airlines and the three responses "agree/neither/disagree". There results were not significantly different from those expected by chance, thus returns were combined across airlines for later analyses.

Next, each of the 36 questions was separately analyzed for airline differences by constructing a 3 (airline) X 2 (agree/disagree) contingency table for each of the 36 questions. The "neither agree nor disagree" category was omitted because it typically is used to indicate an inability to respond to the question as well as a neutral feeling about the statement. The questions for which the pilots of different airlines gave similar answers and dissimilar answers are shown in Table 4. The chi-square probability should be interpreted as the probability that the airlines had identical responses to the questions.

Captains Versus First Officers Each of the 36 questions was examined to determine if captains and first officers responded differently. This was done by constructing a 2 (captain/FO) X 2 (agree/disagree) contingency table for each of the 36 statements. There were 11 statements in which the captains and first officers agreed (see Table 5), and there was significant disagreement on two statements: the captains agreed (and the FOs disagreed) that the autoland capability enhances safety, and that "automation frees me of much of the routine, mechanical parts of flying so I can concentrate more on managing the flight".

Total Flying Time and 767 Flying Time An analysis was performed on the answers received to the 36 opinion questions to determine the correlation of total flying time, 767 flying time, and captain/first officer differences with these answers. This was done by performing a discriminant analysis to see if the three variables could discriminate between the two categories (agree/disagree) on each question. While there was some effect for a few statements (e.g., 767 time predicted agreement with the statement "I can find the exact location of important controls and switches without any hesitation"), in general, the percentage of correct classifications of responses on the basis of these three variables was always less than 70%, so there seems to be almost no detectable relationship between the agree/disagree responses and the three variables. Note, however, a contingency table analysis did detect differences between captains and first officers on two of the 36 questions (see above).

Factor Analysis The responses to the 36 questions were subjected to a factor analysis (there were 96 complete responses for this purpose). An examination of the percent variance explained versus the number of factors showed no significant "knee" in the curve, but that 8 factors explained slightly more than 60% of the variance. These 8 factors were then rotated nonorthogonally to simplify the interpretation of the loading matrix; the factor loadings are shown in Table 6. This analysis is performed by the statistical program; it sorts the 36 questions by the magnitude of the loading, if the loading is greater than 0.5 and sets loadings of less than 0.25 to zero. The questions below the dotted line in the table had the largest loading on that factor although the loading was between 0.25 and 0.50 in magnitude.

It is encouraging to find that the factors are easily identified, but discouraging to find that a large number of factors are required to explain the variance. This seems to be another manifestation of the complexity of the human factors of automation.

Interviews and Meetings

In addition to the results previously reported under the open-ended questions, the following points emerged in discussions with the check pilots during interviews or meetings:

1. Several of the pilots would have liked more training with the AFDS and Mode Control Panel.

2. The first few trainees did not have a good grasp of the FMS/CDU when they reached line training, but this situation improved after each airline gained experience.

3. Two check airmen commented on the duties other than flying. Both felt that some crew members might get overloaded if these duties were not spread out in time. This was especially true when some equipment (e.g., ACARS) was not working. One check airman said that the two man crew should be given extra consideration (e.g., different flight-plan forms, equipment to carry).

4. Some crew members have had difficulty adapting to the two man crew concept. This seems to depend substantially on previous experience, e.g., narrow-body two-man experience versus wide-body three-man crews. One first officer said "there is nothing worse than a three-man-captain in this two-man airplane", indicating, as others did, that the captain must take an active role with extra duties when he is the pilot not flying.

Cockpit Observation

The experience of riding with crews on normal line trips was an extremely important part of the study and yielded information and insight that helped organize many facets of the study. Although no quantitative data were taken (as per the ground rules for the study), the following points were noted:

1. The pilots were extremely enthusiastic about the airplane, and took pride in its performance and the capabilities of the equipment.

2. They were quite facile with the CDU for some tasks, e.g., building new waypoints for abeam fixes. Their performance in other CDU operations was more variable, such as setting up crossing fixes, and depended on their experience level.

3. On at least four of the segments we experienced the early-capture-at-low-altitude phenomenon reported by the pilots. In every case, both pilots were surprised by the sudden reduction in thrust as the aircraft leveled off, even though they had

selected a higher altitude by that time.

4. There were many occasions when it was observed that the automatics were not performing the task desired by the pilot. Most of these situations were minor discrepancies and were resolved by reprogramming the AFDS or FMS. A few of the pilots turned the autopilot completely off and hand-flew while re-engaging the systems. In at least six other instances, the pilot flying tried to rectify the situation by changing modes or setting new values in the AFDS or FMS, but these actions either did not immediately improve the situation or they made matters worse. In these cases the pilot seemed to become more uncertain of the true situation as he did more programming.

Incident Reports

Two incident reports were examined for the relevant human factors and automation elements.

The first incident involved an unselected mode change from Flight Level Change (FLCH) to vertical speed with subsequent airspeed decay. The alerting and warning system remained silent until the appropriate angle of attack limits were reached. Then, as the pilot described it, "all hell broke loose" with the sudden onset of alerts. The pilot reported he was able to think of several reasons why the airspeed indicator was incorrect, even though it was correct. This follows a human tendency to retain the previous hypothesis during these first few seconds.

Another crew member was involved in an in-flight spool-down of engines, resulting in temporary loss of the CRT displays. When the CRT displays were present, the EICAS was filled with messages, and he had difficulty assimilating the information except for the only red message (a cabin altitude warning). He could not discriminate between the second-level caution messages (yellow, starting in the left margin) and the advisory messages (yellow, indented one space from the margin). Furthermore, he had many questions: "I turned on the APU, is it coming up to speed or not? Are the engines really running or are they windmilling?" He felt another crew member might have been useful, not as much for executing procedures as for helping diagnose the problem.

DISCUSSION

Pilot Acceptance of the New Technology

The Airplane in General

The pilots feel positively about the airplane. More than 86% agreed they "enjoy flying the 767 more than the older aircraft" (#11). In response to a statement (#34) about the enjoyment of hand flying, one pilot remarked "It's a sweetheart--tough to turn it over to automation!" This enthusiasm was also evident during the pilot interviews and the cockpit observations when the pilots also mentioned the aircraft performance (high climb rate and cruise altitudes) and the low fuel consumption.

The New Cockpit Technology

The pilots also seem accepting of the new cockpit technology, they choose to use it, and they find it helpful. Over 87% say they "like to use the new features of the 767 as much as possible"(#18), 79% "use the automatic devices a lot because I find them useful"(#10), although 31% also agreed to some degree that they "use automatic devices mainly because the company wants me to"(#35).

The items mentioned by the pilots are shown in Table 2. Particularly noteworthy is that the general capabilities of the AFDS, FMS/CDU, and EICAS are mentioned, suggesting their general agreement with the functions and implementations. Specifically mentioned items, such at the map display and autothrottle, are also heavily used as seen in the Frequency-of-Use table (in spite of their complaints about the implementation details of the autothrottle).

Workload

The pilot acceptance of the new cockpit technology, with respect to workload reduction, seems divided into two groups: those who say it *reduces* workload, and those who feel operating the devices *creates* a form of workload. This is reflected in the divided responses to several questions: 47% agree and 36% disagree, that "Automation reduces overall workload" (#32); 53% agree and 37% disagree that "automation does not reduce overall workload, since there is more to keep watch over" #15; yet 79% agree that "I use the automatic devices a lot because I find them useful"(#10), regardless of any workload penalty. A workload issue for which there was a significant difference between captains and first officers seems based on their different roles: captains agreed more, on the average, and first officers disagreed more, on the average, that "Automation frees me of much of the routine, mechanical parts of flying so I can concentrate more on 'managing' the flight" (#24).

Equipment Reliability

Pilot opinion about the reliability of the equipment was measured by some of the attitude questions and roughly one-fourth of the pilots expressed some concern. Twenty percent of the pilots disagree with the statement "The new equipment is more reliable than the old" (#29) (45% agreed with the statement, and 35% neither agreed nor disagreed). Similarly, 27% agreed that they were "worried about sudden failures of the new devices like the FMS computer and the CRT displays" (#9), although the majority, 64%, disagreed with the statement;

and 26% agreed that they "have serious concerns about the reliability of this new equipment," and again the majority disagreed (62%).

Skill Maintenance

Maintenance of flying skills was a concern of the pilots. This appeared in the questionnaires and in the pilot interviews. For example, 87% agree that they "hand-fly part of every trip to keep my skills up" (#14), and 80% agree that "pilots who overuse automation will see their flying skills suffer" (#18). Interestingly, this concern for other pilots did not always carry over to themselves because only 63% agreed that "I am concerned about a possible loss of my flying skills with too much automation" (#31). It is felt, however, that some pilots did not agree with this statement ***because*** they do a lot of hand-flying.

The Frequency-of-Use table shows that the pilots, in general, hand-fly during transition and enroute climb (especially at the lower altitudes, as observed on line flights) and in the terminal area and final approach phases.

Features Disliked

There were few features or concepts that the pilots did not like, although there were features whose implementation, they felt, needed improvement.

FMC Response Delay A large number of pilots felt that the response time for the Flight Management Computer was excessive. When a specific instance was mentioned, it usually involved complying with ATC requests while maneuvering in the terminal area. Although some of the pilots have learned that they can "type ahead" of the FMC, that is, push the appropriate buttons before the display requests the information, no pilot said he did this in the terminal area when rapid, accurate responses were required, perhaps because it has the potential for committing errors.

Mechanical/Electrical Checklists Two of the participating carriers used cardboard checklists, and one used a mechanical checklist. Pilots of the first two carriers felt some aid would be useful, especially as one pilot commented, it is difficult for a two man crew to get through a checklist without some form of interruption. Many of the pilots felt that having the checklist displayed on the EICAS would be beneficial. Perhaps so, but previous experiments (Rouse and Rouse, 1980) have found that simply transferring material to the CRT does not necessarily improve performance. It should be noted that the presence of the air-start envelope parameters on the EICAS is not inconsistent with the concept of checklists on the CRT.

Location of Circuit Breakers and Spare Bulbs Several pilots commented on the inability to reach circuit breakers and spare bulbs while remaining in their seat. This appears to be a result of having to pull circuit breakers frequently during the early months of line operation (to remove nuisance EICAS messages). The need to do this has been decreasing as system parameters are adjusted.

Although the indicators have more than one bulb, one pilot reported having both bulbs in the landing gear indicator burned out. The cockpit design philosophy clashes with the reality of line operation at this point: should the pilot continue the landing without leaving his seat, or should he get up to replace the bulbs? Only more experience can answer this question.

Control Wheel Steering This autopilot mode was rarely used by the pilots, and some said its use was discouraged during training. Several reported in interviews that it was "rachety," and "abrupt." My experience with pilots of other wide-body aircraft, who also seem to ignore control wheel steering, suggests that there is more than rough performance behind this choice.

From a human-factors view, CWS has the disadvantage that it alters the stimulus/response characteristics of the airplane, i.e., control column movement to pitch-attitude response. This has the potential for causing "mode" errors, where control movements are generated for one mode, but the other mode is active. Discussion with pilots during the interviews revealed another aspect: CWS, the analog of the pitch/turn knob and/or vertical speed wheel of older autopilots with a "manual" mode, does not give them the appropriate control for certain phases of flight. In particular, it can be difficult to do the maneuvers the pilots wish, e.g., Visual Meteorological Conditions (VMC) maneuvering in the terminal area. This seems to be a characteristic of all aircraft that have Mode Control Panels and CWS. Consider the following task: flying a VMC departure down a river that requires holding altitudes from time to time. This is a case where it is desired to regulate bank angle, instead of heading. This is easily done with a turn knob (which controls bank angle) and vertical speed wheel with altitude-hold detent; it is performed with one hand resting comfortably on the center console without looking at the controls. It is difficult to do the same maneuver with Mode Control Panels that have CWS; or heading select (this must be turned slowly to modulate bank angle) and a vertical speed wheel, two separate controls at arms' length.

Points of Confusion and Surprise

This section will discuss the items reported by the pilots that relate to their operation of the Autopilot/Flight Director/Autothrottle and the Flight Management System. The items reported by the pilots about the operation of the CDU will be deferred to the section under training.

Autothrottle-V/S-SPD Interactions

About 25% or the pilots reported experiencing some confusion, or seeing others become confused about the interaction of the autothrottles and autopilot. The source of this confusion seems to be twofold.

First, the thrust/elevator combination is a complicated interaction in any aircraft, and it recalls the seemingly endless debate about controlling speed/altitude with throttle/elevator. Obviously, both strategies are possible in climb and descent. (There is agreement in some regimes, such as constant altitude: elevator controls altitude, thrust controls speed.) When these functions are automated, then, confusion and surprise are likely to follow if the pilots are not aware of the modes actually in use. The now-classic situation for the 767, reported by 7% of the respondents but experienced by almost everyone, is the situation of a high climb rate close to the ground with a low altitude restriction. The autopilot "captures" the selected altitude about 1500 ft below that altitude, and switches from a mode where autothrottles are holding climb thrust and elevator is controlling airspeed, to a mode where the throttle controls airspeed and elevator controls altitude. It seems that just after altitude capture, an event that is not noticed by the pilot flying because he is also looking outside, an ATC clearance to a higher altitude is received. The new altitude is selected, but instead of continuing the climb, the aircraft levels off at the "old" altitude and the throttles come back to maintain the previously set, but not yet changed bug speed (about 170 knots).

The second proposed reason for the confusion of the autopilot/autothrottle interactions, is that this design has more capabilities than previous systems had. The autothrottle is almost always "armed"; in this state, it can become engaged, e.g., by engaging the SPD mode, even though it had been turned off with the throttle-mounted switches. Most pilots are used to autothrottles that can only be engaged by an autothrottle switch. The response to the questionnaires and experience in line observation suggests that there is some uncertainty about the conditions that will allow the autothrottles to become engaged. In addition, the throttles seem to come out of idle during descent at times that the pilots feel are inappropriate.

Almost 10% of the pilots reported some discomfort with the speed synchronization at the time the Flight Level Change (FLCH) mode is engaged; FLCH is designed to climb at the existing IAS and climb thrust. The reason for the confusion seems to be that the SPD window shows a value at the time FLCH is engaged, but this value has no bearing on FLCH operation since the displayed speed automatically changes to the existing speed when FLCH is engaged. These pilots felt that FLCH should hold the speed displayed in the window, instead of the existing speed. Perhaps the confusion arises because the other numerical parameters on the mode control panel (altitude, heading, even speed itself) operate as selected, not held, values.

It is difficult, from the available data, to allocate the the autothrottle/autopilot confusion among the several possible sources: system design, system implementation, training, and lack of experience with the aircraft.

AFDS Turns "Wrong Way" or Does Not Capture

Nearly 20% of the pilots reported that at one time or another, the autopilot either turned the wrong way (usually on LOC intercept or when passing over a waypoint), or did not capture the desired route or course. It is impossible from the reports received to attribute these occurences to a lack of system knowledge, incorrect programming of the system, or equipment malfunction. Even if the pilots could be contacted for more information, it would be difficult for them to recall all the pertinent details, and in addition, they may not know what caused the anomaly. Some pilots, in their response to the question "Have you ever been surprised by the automatics" answered in the affirmative, but said they never had the time to determine why.

One check airman suggested that an incorrect setting of the FRONT CRS knob on the Instrument Landing System (ILS) receiver would cause the aircraft to turn the wrong way on LOC intercept; tne aircraft will start turning to the incorrect course, but the ILS signals will eventually cause the aircraft to track the localizer correctly. (One respondent mentioned he felt the ILS receiver was too far from the normal scan pattern, and so an incorrect setting might be missed.) There is also the possibility, mentioned by another check airman, that the appearance of the trend vector and the wind correction both contribute to a perception that the aircraft is turning away from the localizer when it is not.

Reports of turning toward the approach course before reaching it may possibly be attributed to capture of a localizer sidelobe. Reports of turning the wrong way after passing a waypoint are hard to explain, except as postulated by one pilot, that perhaps the autopilot had been following the alternate route in the FMS.

The causes of reported "failure" of the FMS to capture a course are difficult to determine. It is true that several preconditions must be satisfied before capture will occur, and it was noted that not everyone was aware of these preconditions during the early phases of operation. Still, equipment malfunctions or idiosyncrasies cannot be ruled out as contributors to the reported instances.

Use of the Wrong Control

Pilots report using the wrong control knob, especially the heading knob for the speed select knob, and vice versa. This seems to occur during the first few hours on the airplane, and disappears with exposure; there were no occurrences observed on the line trips.

Unselected Mode Changes

This phenomenon was reported by 12% of the pilots, with all but two reporting a change to vertical speed, and the others reporting a change to heading hold; both are the default modes of the autopilot. One incident (to be discussed later) was precipitated by such a change. Most of these seem to have been of hardware, not operational, origin.

The level off at FL180 was a singular report. Before this report was received, an engineering pilot from a participating carrier noted that it might be possible to obtain such a level off if the altimeter set knob was turned fast enough and far enough (as might happen while passing through FL180) to cause the altimeter needle to move in the other direction.

Training

Introduction of a New Aircraft

The demands placed on a training department during the introduction of a new aircraft are great indeed. Their work starts long before certification, when the curriculum, slides, and tapes are designed with the manufacturer. From the time spent in ground school when the participating carriers were training their initial crews, it was obvious that their job was a difficult one: by necessity, much of the information they needed was not available, and the job of updating and inserting material is a never-ending one. This was compounded by the change from a three man to a two man cockpit only months before certification. In addition, the training staff must respond to the experience of their line instructors.

Conversations with personnel involved in the transition training suggested that pilots felt the material fell naturally into three topics: aircraft systems, the Autopilot and Mode Control Panel, and the Flight Management System. In some sense, the same was true for the instructors and program developers. Both the pilots and instructors seemed more at home with the aircraft systems, and these were learned without any appreciable difficulty even though they sometimes contained more automation than previous systems; e.g., electrical source selection.

Some pilots and instructors had previous experience with mode control panels. Instructors felt strongly that this previous experience made the transition easier for pilots with this experience.

The Flight Management System was entirely new to most instructors and pilots. Although some had prior experience with inertial navigation systems, the extensive capabilities of the FMS, and its integrated nature were completely new to most individuals. The following comments, from the questionnaire, reflect this view.

> "[The FMS/CDU] system is complex and so completely different."
>
> "I believe that the FMC was the most difficult to understand during ground school and the first few periods in the simulator. My classmates felt the same way."

FMS/CDU Training

When asked on the questionnaire what material they wanted more or less of in training, the strongest responses were requests for: more FMS and CDU training (in general); more "hands on" experience and training with the FMS/CDU; more line-oriented CDU exercises; and less nonoperational CDU material. These comments were confirmed by several line training pilots, who, in the early phases, felt that the pilots arrived for line training with less than desirable knowledge and skills about the FMS/CDU. No pilot who responded to the questionnaire had training with a Flight Management Systems Trainer (FMST), although two of the airlines had ordered such a device. Most of the FMS/CDU exercises were done on part-task, computer-graphics terminals that illustrated the CDU keyboard and display. One airline attached a CDU keyboard and display to the instructional station; another developed a multi screen presentation to show, with slides, the mode control panel and the EADI/EHSI; the FMS/CDU was depicted on an interactive computer graphics terminal.

The difficulties of conducting the FMS/CDU training seemed to have come from several sources. First, there were many new concepts for the pilots to learn, e.g., navigating from autotuned radios, not from a single radio. Second, although it is beyond the scope of this study to identify the conceptually difficult aspects of the system, the organization of the information, and the naming conventions seemed to cause problems for some people. Third, and perhaps most important, there was no training device that (from the pilots' view) was an adequate simulation of the real FMS/CDU; see the comments below on Computer-Aided Instruction.

Relevance of Material

It can be seen from the responses that many of the pilots wished they had had more "realistic" or line-oriented material in their FMS/CDU exercises, and/or less material on features that were nonoperational. This latter request seems to have arisen from the scheduled versus actual introduction of equipment capabilities. At first, the full capability FMS was to be introduced, and training reflected this. Subsequent schedule slippage resulted in the initial aircraft being delivered without a VNAV (Vertical Navigation) capability; an "interim" VNAV package was later released, and the "full" VNAV capability is now scheduled for release in 1985. Thus, while training traditionally teaches some material before it is available, the actual evolution of the FMS made the VNAV material particularly irrelevant in the pilots' view.

In addition to the material they received that they did not need, the pilots also felt that they did not receive material they could have used. In some sense this is a continuing point of contention between line pilots and training departments. In the case of the FMS/CDU, pilots revealed in interviews that they did not know how to deal with tasks such as crossing restrictions until after they started line flying. Although one can argue that these functions would have been covered by the VNAV system, pilots were not given an interim method and sometimes did not receive the material in line training. Another item mentioned in the interviews, and the questionnaires, was a last-minute change in approach assigned by ATC; removing old information seemed to be as much of a problem as selecting the new approach from the menu.

Computer-Aided Instruction--
Impressions and Lessons Learned

During the course of attending ground school at the three participating airlines, certain impressions were obtained from first-hand experience and the comments of classmates. These impressions are being presented here, not to imply that one training method or training device is better than another since many other factors (e.g., current staffing levels, staff capabilities, budgets, etc.) must be incorporated into a decision to use a particular training method or device. Rather, they are given in the context of experimental data so that consideration to these points can be given in the future.

Realism A good deal of CDU instruction was done with computer-graphics terminals. This seems to be a reasonable teaching device for these tasks, since it is possible to create a good representation of the CDU on the graphics terminal and the touch-sensitive screen allows pilot actions similar to the real keyboard. The same computer system and programs were used by all three participating carriers and provided a basis for comparison.

The pilots felt the primary drawback of the device was the lack of functional realism, i.e., at a given point of the exercise, there was usually only one allowed sequence of responses, whereas on the real system, much more freedom is available. The trainee was never sure whether the inability to do what he wanted to do was due to his lack of understanding or a limitation of the training device. It is recognized that this is a tradeoff involving programming effort, but the frustration level of the pilots became high at certain times. One carrier minimized this effect by having an instructor present with each crew as they went through the exercises. Before the pilot would start a sequence not allowed by the program, the instructor would ask his intentions; if they were inconsistent with the computer program but consistent with the real system, the instructor would say "Yes, you can do it that way on the airplane but this program is looking for another way, so do it this way...." This approach, while requiring more instructional manpower, eliminated most of the frustration with the training device.

In summary, it seems important to have the training device respond as much like the real device as possible without any artificial restrictions; this will remove the extra uncertainty in the pilot's mind as he is learning, and will more quickly increase his knowledge of the system as he explores and makes mistakes using the system. Manuals for complex systems rarely tell what you cannot do.

Self-Paced Instruction One carrier had most of the material on a computer instruction system tied to a mockup of the relevant panels, with backlighting controlled by the computer system. Conventional slides and audio tapes were also available to use as the pilots wished, ground school instructors were available to answer questions, and meetings with rated pilot/instructors were also used. The success rate on the oral exams was excellent. Originally, the pilots were instructed to proceed at their own pace through the computerized material over a period of more than a week, and were not given feedback on their pace.

The pilots felt positively about the flexibility of scheduling their own time, but wanted feedback on their progress. Most pilots felt they hurried through the multiple choice questions without much reflection. First, they did not know their progress compared to the norm, and they knew that a significant effort would be required if they got behind. Second, without pacing of any kind (as might come from an audio tape) the NASA observer felt, as did others, that there was a tendency to "rush" through the questions, just to "finish." It seems that daily goals and some pacing (perhaps controlled by the student) would be useful.

Prompting and Feedback No computer instruction that was used by the NASA observer allowed the student to control the level of prompting he received. At some point in the learning process, students reached the point where they felt they knew enough to try a solution without any prompting or help, but they had no control over the prompting.

Prompting in computer-aided instruction is similar to a "help" capability on interactive computer systems. However, with these systems the user is allowed to select the level of "help" he receives, or he receives help only when he asks for it. Letting the user select the help level is a feature that has evolved after many years of trying, without success, to "compute" the level of help needed from the user's previous experience and mistakes. User-selected help level is easier to program, and gives the user more control over the process; it would seem to be a useful feature to have in these instructional programs.

The "three-screen" presentation developed by one airline was a useful step in integrating the many interactions of the FMS and autopilot systems. It was paced by an audio tape, and the NASA observer felt that one feature, in particular, was extremely useful as a teaching method. He knew enough to select the correct switch or knob to get through the exercise, but the audio tape and displays pointed out the many ramifications and concomitant system responses to those actions. This was extremely informative, and it would seem to be a useful goal of any training system dealing with interactive, integrated systems, since it reinforces the interactions and helps the student "build" his internal representation of the systems.

Lectures vs. Computer-Aided Instruction The training results obtained by the three carriers, and the data from the questionnaires, do not suggest a superiority in transferring knowledge for the lecture format or the (primarily) computer-aided instruction. No pilot answering the questionnaire mentioned the positive aspects of flexible scheduling, although several students mentioned it during casual conversation. The 10 pilots who said they wanted less computer-aided instruction and more communication with instructors and classmates did not indicate whether they would give up schedule flexibility for these missing features.

With the passage of time, it seems that the "pure" computer-aided instruction of one carrier has evolved to a program containing more interaction with the rated instructors. Moreover, the airline that traditionally used the lecture format has made extensive use of computer-aided instruction for the first time. Thus it seems that all airlines are evolving their training to a similar mix of computer-aided and face-to-face instruction.

Is There an Information Gap?

Observations in ground school, data from the questionnaires, and conversation with the system designers suggest that not all the desired information is making its way to the line pilots, at least during the introductory period.

During the third ground school attended by the NASA observer, the instructor was describing the procedure to set up the FMS/CDU. He noted that it had been mysterious to him until he "discovered" that, once on the initial page, "if you press the LINE SELECT key on the lower right, it will lead you to the next logical step; if you want to back up, press the LINE SELECT key on the lower left". Each line key is labeled with a prompt for the appropriate "page" in the sequence. Prior to that time, the NASA observer had not remembered such a simple, logical "rule" in previous ground-school material, although it may have been there. It seems that the system designers had intended that this technique be used, but it was apparently dropped somewhere along the way.

Another example involves the use of the FMS/CDU in terminal area operations. A significant number of pilots reported on the questionnaire that they observed or experienced confusion in responding to rapidly changing ATC requests, and that the FMC responds too slowly under these conditions. Discussion with the cockpit design team revealed that they had anticipated the necessity for rapid response, and had incorporated features in the design that would allow pilots to immediately respond to ATC and defer CDU interaction. No explicit instructions for this situation were observed in ground school, simulator sessions, or line training flights, so it may be that the recommended procedures are not being transmitted to the pilots. Alternatively, the recommendations may may have been tried, but found inadequate.

It is interesting to note that both of these examples might be classified as techniques, and techniques are of great interest to the pilots and the designers. This is especially true when complex systems are involved because the right technique can greatly simplify a system. But in addition to techniques, there is a large amount of detailed material to be learned, and it is not surprising that techniques and other concepts get "lost" somewhere between the designers and the pilots.

Computer Concepts

Two of the questionnaire respondents asked for some instruction on computer concepts.

> "Ground school should not teach just function of the CDU/computers, but a philosophy of computer applications and programming as applicable to our aircraft. This was done when the [new jet-turbine technology] B-707 was introduced in 1958. Now that everyone is jet oriented, this is not necessary. So today, the computer is new and should be taught until everyone has the 'idea'".

> "For those of us with no computer literacy (buzz word) a 10 minute dissertation on computer functioning would help. Actually, just the thought that the damn thing only does what it is told would save some errors."

One pilot suggested an even broader scope.

> "From what I've seen so far, we could use a bit more emphasis on the 'background' of some of the automatics to better able a crew to understand what's happening or not happening when things don't go as programmed..."

This type of instruction would certainly be consistent with the idea of creating a "schema" or framework about computers or automation, into which detailed information would more easily be assimilated.

Flying The New Technology

Distractions

Several incident reports have appeared in the last 2 yrs that have a common theme. The incidents involved transport aircraft with higher levels of automation. A typical scenario proceeds as follows: the automatics are on and doing their assigned tasks more than adequately. Something happens to attract the crew members' attention; e.g., crossing a navigation fix, distractions from other crew members, etc. These distractions are typified by high levels of cognitive (not perceptual) activity. During this time, something happens to the operation of the automatics (unselected mode change, unusual environmental conditions) that requires intervention by the crew. This need goes unnoticed because of the human tendency to deal with one task at a time, and the high cognitive level of the "distractor" task that consumes most (if not all) of the crews' attention.

In some respects, this is exactly the tendency that must be overcome for a pilot to become proficient at instrument flying. Instrument flying involves "learning" (1) to extract the necessary information from a display as quickly as possible, and (2) not to fixate on one instrument, but to sample all instruments with appropriate frequency. Instrument flying breaks down when the pilot becomes "locked on" to an important piece of information and concentrates on resolving one anomaly to the exclusion of the other parts of the task (e.g., neglecting airspeed control during a difficult localizer intercept).

The experience with all aircraft having more sophisticated on-board devices leads us to suggest that pilots must learn not to neglect the basic aircraft parameters. In other words, new scan patterns must be developed, so that the pilot can deal with "distractions" as well as with monitoring. During instrument flying, the pilot receives immediate feedback if he fails to properly scan the instruments, since the aircraft will quickly deviate from the intended course. The pilot receives feedback about improper monitoring, however, only when the automatics fail to operate as intended *and* when he is otherwise distracted. These two conditions do not often occur at the same time, and so feedback on improper monitoring is rare.

Turn it off!!

On several of the line observation trips, the NASA observer noticed the following. When things did not go as planned, or when the pilot was "surprised" by the automatics (e.g., the early altitude capture with high rate of climb), the pilot would try to "program" his way out of the anomalous condition. The situation would sometimes get worse and more confusing, not better. It seemed to the observer, on these occasions, that the pilot would have made a smoother and less distracting recovery by simply turning off all the automatics and then turning them on one at a time as needed. This strategy has the advantage that one immediately starts from a known condition, a hand flown airplane, and it is much easier to assess the automatics as they are engaged one at a time.

A captain involved in an incident spontaneously volunteered that his experience would not have degraded to the level of an incident had he turned everything off when he became confused and started "fresh".

The tendency for some pilots to program a recovery, and not "turn it off." was also confirmed by interviews and discussions with line training pilots and check airmen. It does not appear to be a fascination with the new equipment. Instead, it appears to be a habit learned during simulator training and most line training, where the instructor's job is to ensure that the student learns the operation of the automatic equipment. It seems to be taken for granted that the student knows there is an airplane behind the panel, and that the student knows when to turn it all off.

A questionnaire respondent felt the need for this training when he asked for more training "to turn off the auto system and take over manually at any place or time."

One line-training captain said he used the following metaphor for new captains (it has some disadvantages when applied to first officers!): think of the automatics as a crew member brand new to the airplane; take over from the automatics (i.e., turn it off) any time you would take over from the new crew member.

In summary, it appears that pilots need "turn it off" training because of the tendency (perhaps due to prior training) to program their way out of an anomaly, but this often makes matters worse.

HUMAN FACTORS PRINCIPLES:
CONFIRMATIONS, A NEW PRINCIPLE, AND RESEARCH ISSUES

This section describes the information gleaned from the study that has a bearing on the more general human factors issues. These have surfaced as confirmations of existing principles, a suggestion for a new principle, and topics for new research.

Confirmations

Minimize Mental Operations

It has been proposed that displays be designed to minimize mental operations or transformations (National Research Council, 1982). This principle seems to have been confirmed by several examples of the B-767 aircraft. First, the map display gives an excellent representation of the horizontal situation, with minimal effort. It is well received by the pilots and heavily used, testimony in itself. (The ease of use and acceptance come as no surprise to the military pilots and researchers who have been using map displays for more than 15 years.)

Another example of a display that minimizes mental operation is the altitude arc. This shows, on the map display, the geographical position at which the aircraft will reach the altitude selected on the mode control panel. This display eliminates the necessity to continually extrapolate the flight path, by rules of thumb, to determine the position where the aircraft will be at the desired altitude, i.e., will the crossing restriction be met, or will the descent be too steep resulting in wasteful use of fuel at low altitudes.

Human Error

As presented in an earlier work (Wiener and Curry, 1980), one goal of automation is to eliminate human error. It was our contention that this is difficult, and automation will change only the locus and type of human error. This principle has not been disproved by observation of automation on the B-767, since the operation of this aircraft has not been without incident where human error was a contributing factor. There certainly are not enough data, nor is it a meaningful exercise, to determine if it is "better" or "worse" than other aircraft from this standpoint.

The accident involving the Air New Zealand DC-10 in the Antarctic, in which ground-based computer errors had been made while creating and distributing flight plans, may be a precursor of this change of locus of human error. There is scant evidence that such errors are occurring with the current database or systems on the B-767. There was only one reported case of an anomaly that apparently involved a stored flight plan taking a 50-mile off-track excursion to an obscure waypoint halfway through the cross-country flight plan.

A New Human Factors Principle for Automated Systems

This section presents some information that appears to be worthy of consideration as a human factors principle of automation.

Display Data, not Commands, for Control

There are three examples that suggest that displaying data, not commands, is more useful if the pilot can take appropriate control action without significant mental transformations or effort. The first example is the Heads-Up Display (HUD) format proposed by Bray (1980), where inertial flightpath angle and scaled ILS raw data can be combined to allow easy ILS tracking. The second example is the track-up map display and trend vector on the 767 (functionally similar to the HUD format). The third example is the altitude arc discussed above. In each case vehicle state information can be used to generate corrective control actions with little or no mental effort. Moreover, there is a great deal more flexibility in accomplishing flightpath objectives with the data display compared to the command display.

The issue seems to be this: A command-generation device needs to know the objectives of the maneuver. These always have to be transmitted to the pilot or to the command generation system, either implicitly or explicitly. A data presentation, on the other hand, needs no such transmission of goals, and it allows the pilot the flexibility to use more knowledge than would be feasible to incorporate into the command generator. Consider the following fictitious example of how a pilot could use the altitude arc on the B-767 map display: As they prepare to descend into O'Hare, the pilot thinks, "I know ATC is going to clear me to cross XXX at 11,000, but it is Friday afternoon, the traffic is heavy, and I will probably get vectors off course for spacing. If I keep it a little high, I will not get down too early even with the vectors; the altitude arc will tell me how I am doing with the crossing restriction when I am off course. If ATC doesn't give me vectors, I can push it over and know that I'll make the crossing restriction without any trouble."

Thus, displaying data (not commands) for control removes the necessity for the pilot and command generator to transmit and/or have common objectives, and it allows the pilot flexibility to modify his goals for existing conditions.

Research Issues

Display of Mode Target Values

It is not unusual to see a pilot "fighting" the automatics, especially autothrottles: he pulls them back, they advance, he pulls them back again, and they advance once more. Obviously there is a goal conflict. In a system with many complex interacting modes, it seems plausible that explicit display of the goals or target values, as well as the modes, would be an aid in interpreting the actions of the automatics. In an aircraft context, such displays might take the following form:

with target values	without target values.
THRTL=250KTS	SPD
ELEV=10,000FT	ALT HLD

or

THRTL=CLIMB EPR	EPR
ELEV=V/S=1500FPM	V/S

It is true that aircraft autopilot and flight management systems usually display the target values, but such data exist in a variety of places and not necessarily near the mode annunciations; moreover, mode annunciations do not always indicate who is doing what to whom. The questionnaire responses suggest that pilots view the central location of mode annunciation on the EADI as a positive feature; displaying the target values, along with the modes, has the potential for further enhancing a rapid determination of system state.

Human Behavior and Information Processing for Partial Automation and Monitoring

It was described earlier how pilots, as humans, tend to become distracted from the monitoring task. The possibility of more and/or different training was raised as a possible remedy, although it seems difficult to achieve consistent gains this way. It is recommended that the influence of system design be investigated as an alternative method to alleviate the problem, For example, lower-level advisory messages such as degrading airspeed, rising engine, or cargo temperature, may improve monitoring performance. The next section discusses these possibilities.

The human information processing requirements are different for manual flying and flying with automation, and a better understanding of the differences would be useful to designers. For example, altitude is continually scanned when pilots manually fly the airplane; this in turn, may serve as a reminder for the level-off altitude. There is no such persistent requirement when flying with automation, but one can argue that automation frees human resources to allow better monitoring. If this is so, why have there been so many spectacular lapses of monitoring in over the years? Pilots feel that flying with partial automation is different, and requires more monitoring. In one sense, it should be no different from monitoring another crewmember as he flies, but pilots do not think of it that way. Why is this so? Research is required to unravel these paradoxes.

The time-dependent aspects of monitoring also should be investigated. One may view flying as the performance of many procedures that are triggered by elapsed time and events. The introduction of automation introduces new events and alters the elapsed time of familiar events. It is even more difficult when the operators are not exactly sure what events may be triggered, and by what. Moreover, the absence of an event is usually more difficult to detect than the presence of an event, so detecting malfunctions from these symptoms is more difficult. System designers need to know more about the useful time intervals of monitoring and other related phenomena.

Alerting Systems

Direct information was obtained from crew members involved in two incidents. Both discussions revealed a need for more information about human interaction with alerting and warning systems.

Trending The incident involving airspeed decay reveals the problematic nature of withholding all alerts until absolute necessary. Other incidents have also demonstrated this. It is human nature to retain the previous hypothesis in spite of alarm indications to the contrary (alarm systems are not always correct, after all). In many instances it would seem that the time it takes to come to a correct diagnosis can, and has been, lengthened by this alerting philosophy. A "trending" philosophy would allow an assimilation of information over time, and may even prevent the situation from deteriorating to the point of normal alarm activation. The drawback of a trending philosophy, of course, is the possible existence of too many nuisance alerts. Thus, the research should explore trending philosophy and determine how to display a large number of low-level advisory messages without being bothersome.

Perhaps the design objective of any alerting system (as told by one pilot) should be this: if the pilot mentally says "thanks" to the system, it was a useful alert; otherwise it is not.

Quantity and Quality of Information The report of the crew member who experienced engine spool-down raises the extremely difficult issues facing the system designers: what information should be given to the pilot; how should it be presented; how should it be prioritized?

At least three research topics are suggested by this incident, although the first is not new. Is there a logical and rational method, from both the designers' and pilots' view, to organize and prioritize the information? Second, is it worthwhile to have a sophisticated on-board system to propose hypotheses and actions to the crew? Lastly, would it be useful to have a database query system to answer questions such at posed by this pilot, e.g., is the APU in a normal start, or are the engines running? The interface to such a query system would be a design challenge, indeed, but a query system might remove the primary need for prioritization and organization of information.

CONCLUSIONS

There are two points concerning the results that deserve particular emphasis. First, the data were taken during the early introduction of the aircraft and the conclusions apply only to that period. Second, although the B-767 was the only aircraft in the study, discussions with operators of the A310 (another new-technology-cockpit aircraft) have confirmed very similar experiences. Thus, the following conclusions, while specifically mentioning the B-767, are likely to be valid for the introductory period of the A310:

1. Most of the pilots enjoy flying the B-767 more than they enjoy flying the older airplanes.

2. The pilots accept the new cockpit technology, and they choose to use it because they find it useful.

3. The pilots are aware of the possible loss of flying skill with the presence of automation, and they hand-fly (usually with flight director) to prevent this loss. The data collected in this study do not indicate any loss of skills.

4. The primary points of confusion or surprise were autothrottle/autopilot interactions; the autopilot turning the "wrong way" or not capturing the course; and achieving desired results with the (FMS/CDU).

5. The pilots felt training for the FMS/CDU could be improved, and they especially wanted more "hands on" experience. More training on the mode control panel, and more hand flying were also mentioned.

6. Information, especially "techniques," may not always be getting from the system designers to the line pilots

7. Flying *any* aircraft with sophisticated equipment and high levels of automation allows distractions that cause a loss of monitoring performance.

8. Many pilots should be trained to "turn it off" and not try to "program" their way out of an anomalous situation.

9. These field data confirm some existing human factors principles, suggest a new principle, and raise questions requiring further research.

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Table 1. Pilot Statistics

Airline	Number of of Captains	Number of of F/Os	Total Time (hrs)			767 Time (hrs)		
			Minimum	Median	Maximum	Minimum	Median	Maximum
A	15	7	8000.0	14000.0	23150.0	17.0	60.0	300.0
B	16	12	8500.0	12000.0	24000.0	20.0	113.0	300.0
C	30	22	4200.0	15500.0	25000.0	5.0	103.5	250.0
All Pilots	61	41	4200.0	13500.0	25000.0	5.0	100.0	300.0

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Table 2. Number of pilots mentioning items on 102 questionnaires

Total Number of Questionnaires 102

Number of Pilots	
	FEATURES LIKED
	AFDS
20	Autothrottle Concept/Speed Control
14	AFDS Capabilities
10	Takeoff Mode and/or EEC
8	Reduced Workload
6	Altitude Capture/Select
	EFIS
42	Display and clarity of information
22	Map display
7	Green Altitude Arc
5	Wind Vector
4	ADI Mode Annunciation
2	Ground speed display
	FMS/CDU
48	System capabilities
2	Route display
	EICAS
35	Quality and quantity of information
6	Engine limits and numbers
3	Monitoring capabilities
	FEATURES MISSING OR NOT LIKED
20	FMC response delay
7	Want electrical/mechanical checklists
7	Circuit breakers and spare bulbs not within reach

Table 2. Number of pilots mentioning items
on 102 questionnaires (con)

Total
Number of
Questionnaires
102

Number of Pilots	
	POINTS OF CONFUSION OR "SURPRISE"
25	Autothrottle-V/S-SPD Interaction
20	AFDS turns "wrong way" or does not engage
19	Using wrong control (especially HDG/SPD)
12	Unselected mode change (10 to V/S, 2 to HDG HLD)
11	Removing route discontinuities and extra information
11	Track/heading on map display
9	Speed sync at FLCH engagement
7	Early altitude capture at high climb rate
7	AFDS-MCP mode (general)
6	FMS/CDU useage (general)
6	Simultaneous speed brakes and landing flaps
5	Changing approaches on FMS/CDU close-in
3	No aural trim indication
3	Holding with FMS/CDU
3	Map drift
2	Use of J routes in FMS/CDU
2	High bank angles at LOC capture
2	Defining waypoints from station
1	Unselected level-off at FL180
	TRAINING
4	Satisfactory as is
More:	
25	FMS/CDU
22	"Hands on" CDU experience
12	Hand flying
8	AFDS-MCP training
7	Practical, line-oriented CDU exercises
6	Aircraft systems
3	Single engine simulator experience
Less:	
10	Computer aided instruction
7	Three-man simulator
3	nonoperational FMS material
2	Phase-of-flight presentation

Table 3. Statements Used for Pilots' Responses

1. I can fly the airplane as smoothly and safely by hand as with automation.
2. Younger pilots catch on to automation faster than older ones.
3. Flying today is more challenging than ever.
4. The FMS/CDU is easy to use in normal line flying.
5. I think they've gone too far with automation.
6. Autoland capability definitely enhances safety.
7. I spend more time setting up and managing the automatics (such as the FMS/CDU) than I would hand-flying or using the old style autopilots.
8. I like to use the new features of the 767 as much as possible.
9. I am worried about sudden failures of the new devices like the FMS Computer and the CRT displays.
10. I use automatic devices a lot because I find them useful.
11. I enjoy flying the 767 more than the older aircraft.
12. I always know what mode the Autopilot/Flight Director is in.
13. I can fly as efficiently as the FMS without its help.
14. I hand-fly part of every trip to keep my skills up.
15. Automation does not reduce workload, since there is more to keep watch over.
16. I can find the exact location of important controls and switches without any hesitation.
17. Automation is the thing that is going to turn my company around and make it profitable again.
18. Pilots who overuse automation will see their skills suffer.
19. The ADI and EHSI displays are always legible and easy to read.
20. I am favorable toward automation in the cockpit - the more the better.
21. Flying the 767 is definitely easier than flying other aircraft.
22. Setting piloting priorities with this new cockpit technology is no more difficult than in our other airplanes.
23. We should have full autothrottles on all the company's aircraft.
24. Automation frees me of much of the routine, mechanical parts of flying so I can concentrate more on "managing" the flight.
25. I have serious concerns about the reliability of this new equipment.
26. Sometimes what the automatics do or don't do takes me by surprise.
27. It is easier to cross-check the other pilot in the 767 than in our other airplanes.
28. Too much automation can be dangerous.
29. The new equipment is more reliable than the old.
30. It is important to me to fly the most modern plane in the company's fleet.
31. I am concerned about a possible loss of my flying skills with too much automation.
32. Automation reduces overall workload.
33. I always feel I am ahead of the airplane.
34. Hand-flying is the part of the trip I enjoy most.
35. I use automatic devices mainly because the company wants me to.
36. The FMS/CDU requires little or no in-flight button-pushing below FL180.

Table 3. Pilot Opinion Summary (% responses by category) (con)

STATEMENT NUMBER	STRONGLY AGREE	SLIGHTLY AGREE	NEITHER AGREE NOR DISAGREE	SLIGHTLY DISAGREE	STRONGLY DISAGREE
1	28	31	12	25	5
2	12	37	28	18	6
3	37	29	14	17	3
4	38	35	5	19	3
5	3	17	18	27	35
6	26	36	17	15	6
7	30	35	7	15	14
8	54	36	6	4	0
9	11	16	10	28	36
10	39	40	16	6	0
11	62	24	7	7	0
12	29	32	8	28	3
13	3	17	18	40	23
14	63	24	4	7	2
15	22	31	10	23	14
16	29	29	10	31	2
17	6	15	39	18	21
18	48	32	6	12	3
19	51	28	5	13	3
20	15	44	17	17	6
21	13	33	24	25	6
22	19	32	10	32	8
23	16	21	41	15	8
24	19	42	16	19	5
25	4	22	13	30	32
26	10	52	8	22	8
27	11	26	30	27	7
28	11	34	29	17	10
29	13	32	35	21	0
30	16	28	33	16	8
31	24	39	8	16	13
32	18	29	17	31	5
33	21	40	10	28	1
34	22	38	25	10	6
35	6	25	27	30	13
36	3	13	6	24	55

Table 4. Contingency Table Comparisons of Responses to Statements (agree/disagree) and Airlines

Statements on which there was agreement ($p > 0.72$)

Probability	Statement number	Statement
0.93	2	Younger pilots catch on to automation faster than older ones.
0.95	5	I think they've gone too far with automation.
0.82	11	I enjoy flying the 767 more than the older aircraft.
0.80	13	I can fly as efficiently as the FMS without its help.
0.72	20	I am favorable toward automation in the cockpit-the more the better.

Statements on which there was disagreement ($p < 0.05$)

0.013	1	I can fly the airplane as smoothly and safely by hand as with automation.
0.015	4	The FMS/CDU is easy to use in normal line flying.
0.037	9	I am worried about sudden failures of the new devices like the FMS Computer and the CRT displays.
0.048	14	I hand-fly part of every trip to keep my skills up.
0.025	16	I can find the exact location of important controls and switches without any hesitation.
0.017	21	Flying the 767 is definitely easier than flying other aircraft.
0.041	26	Sometimes what the automatics do or don't do takes me by surprise.
0.025	29	The new equipment is more reliable than the old.

Table 5. Contingency Table Comparisons of Captains Versus First Officers and their Response to the 36 Statements

Statements on which there was agreement ($p > 0.80$)

Probability	Statement number	Statement
0.85	1	I can fly the airplane as smoothly and safely by hand as with automation.
0.99	4	The FMS/CDU is easy to use in normal line flying.
0.87	10	I use automatic devices a lot because I find them useful.
0.88	12	I always know what mode the Autopilot/Flight Director is in.
0.85	13	I can fly as efficiently as the FMS without its help.
0.91	19	The ADI and EHSI displays are always legible and easy to read.
0.90	21	Flying the 767 is definitely easier than flying other aircraft.
1.00	22	Setting piloting priorities with this new cockpit technology is no more difficult than in our other airplanes.
0.87	23	We should have full autothrottles on all the company's aircraft.
0.85	32	Automation reduces overall workload.
0.84	34	Hand-flying is the part of the trip I enjoy most.

Table 5. Contingency Table Comparisons of Captains Versus First Officers and their Response to the 36 Statements (con)

Statements on which there was disagreement ($p < 0.05$)

Probability	Statement number	Statement	Reasons
0.047	6	Autoland capability definitely enhances safety.	Captains agree more, FOs disagree more
0.043	24	Automation frees me of much of the routine, mechanical parts of flying so I can concentrate more on "managing" the flight.	Captains agree more, FOs disagree more

Table 6. Factor Analysis of Pilot's Responses to 36 Statements

Factor Loading	Statement number	Statement
0.815	25	I have serious concerns about the reliability of this new equipment.
0.806	9	I am worried about sudden failures of the new devices like the FMS Computer and the CRT displays.
-0.661	29	The new equipment is more reliable than the old.
-0.525	22	Setting piloting priorities with this new cockpit technology is no more difficult than in our other airplanes.
0.732	13	I can fly as efficiently as the FMS without its help.
0.727	1	I can fly the airplane as smoothly and safely by hand as with automation.
-0.534	24	Automation frees me of much of the routine, mechanical parts of flying so I can concentrate more on "managing" the flight.
0.462	35	I use automatic devices mainly because the company wants me to.
0.458	7	I spend more time setting up and managing the automatics (such as the FMS/CDU) than I would hand-flying or using the old style autopilots.
-0.447	32	Automation reduces overall workload.
0.409	34	Hand-flying is the part of the trip I enjoy most.
0.327	5	I think they've gone too far with automation.

Table 6. Factor Analysis of Pilot's Responses to 36 Statements (con)

Factor Loading	Statement number	Statement
0.802	16	I can find the exact location of important controls and switches without any hesitation.
0.768	12	I always know what mode the Autopilot/Flight Director is in.
0.727	33	I always feel I am ahead of the airplane.
0.497	10	I use automatic devices a lot because I find them useful.
0.488	4	The FMS/CDU is easy to use in normal line flying.
0.804	14	I hand-fly part of every trip to keep my skills up.
0.753	18	Pilots who overuse automation will see their flying skills suffer.
0.720	31	I am concerned about a possible loss of my flying skills with too much automation.
0.407	28	Too much automation can be dangerous.
0.729	30	It is important to me to fly the most modern plane in the company's fleet.
0.716	11	I enjoy flying the 767 more than the older aircraft.
0.549	20	I am favorable toward automation in the cockpit - the more the better.
0.489	8	I like to use the new features of the 767 as much as possible.
0.458	6	Autoland capability definitely enhances safety.
0.799	36	The FMS/CDU requires little or no in-flight button-pushing below FL180.
0.648	27	It is easier to cross-check the other pilot in the 767 than in our other airplanes.
-0.379	15	Automation does not reduce workload, since there is more to keep watch over.

Table 6. Factor Analysis of Pilot's Responses to 36 Statements (con)

Factor Loading	Statement number	Statement
0.701	23	We should have full autothrottles on all the company's aircraft.
0.515	21	Flying the 767 is definitely easier than flying other aircraft.
-0.451	26	Sometimes what the automatics do or don't do takes me by surprise.
0.448	17	Automation is the thing that is going to turn my company around and make it profitable again.
0.645	19	The ADI and EHSI displays are always legible and easy to read.
0.548	2	Younger pilots catch on to automation faster than older ones.
0.496	3	Flying today is more challenging than ever.

Appendix A

Questionnaire Distributed to Participating Pilots

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Please fill in the information below, and then proceed with the remaining parts.

When you are finished, return the entire booklet in the envelope to:

Dr. Ren Curry
NASA Ames, 239-3
Moffett Field, CA 94035

ID code ___ ___ ___ ___ ___ ___ ___ ___

Your Position : ___Captain ___First Officer

Today's Date : ___/___/___

Date you finished line training: ___/___/___

Total hours flying time : __________

Total hours in 767 : __________

Days since you last flew the 767 : __________

FREQUENCY OF USE

The purpose of this part is to determine how frequently you use certain features of the 767 during various phases of flight.

Enter the percent of your legs on which you use the particular feature for each phase of flight. For example, if you always use autothrottle on takeoff, then enter 100 in the row for Autothrottle and the Takeoff column; if you use autothrottle for takeoff only on 1/3 of the legs, then enter 33 in the Takeoff column.

If it is possible to use a feature in a particular phase of flight, but you never use it because of company procedures, FARs, or your own preference, then enter 0.

If it is impossible or doesn't make sense to use a feature during a particular phase of flight, e.g., "Step Climb" during the takeoff phase, then cross out that "cell" of the table with a large X.

The last column is provided for any comments you may have about why you do or do not use the feature, and/or how you use it.

ID Code __ __ __ __ __ __ __ __

For each phase-of-flight column in the table, enter the percent of your legs on which you use the feature described on the left. If it is impossible or doesn't make sense to use the feature in a particular phase of flight, then cross out that "cell" in the table.

FEATURE		PHASE OF FLIGHT							COMMENT
		Takeoff to 1000 AGL	Transition & Enroute Climb	Cruise	Descent (Cruise to 10,000 MSL)	Terminal Area	Final Approach	Landing	
AUTOPILOT CMD									
CWS									
Hand Fly	no FD								
	with FD								
MCP FEATURES Vertical Speed									
Bank limit--Auto									
Bank limit--man									
LNAV									
VNAV									
FL CH									
Approach Mode									
Autoland									
AUTOTHROTTLE									
DISPLAYS Map mode									
VOR/ILS mode									
Altitude (Green) Arc									
FMS/CDU Direct/Intercept									
Step Climb									
FIX mode									
VOR manual tune									

ID Code ___ ___ ___ ___ ___ ___ ___ ___

For each phase-of-flight column in the table, enter the percent of your legs on which you use the feature described on the left. If is impossible or doesn't make sense to use the feature in a particular phase of flight, then cross out that "cell" in the table.

FEATURE	PHASE OF FLIGHT							COMMENT
	Takeoff to 1000 AGL	Transition & Enroute Climb	Cruise	Descent (Cruise to 10,000 MSL)	Terminal Area	Final Approach	Landing	
AUTOPILOT Hand fly--no FD								
Hand fly--with FD								
CWS								
Vertical Speed								
Bank-limit--Auto								
Bank limit--manual								
LNAV								
VNAV								
FL CH								
Approach Mode								
Autoland								
AUTOTHROTTLE								
DISPLAYS Map mode								
VOR/ILS mode								
Altitude (Green) Arc								
FMS/CDU Direct/Intercept								
Step Climb								
FIX mode								
VOR manual tune								

This is the first version of the frequency-of-use table

ID Code ___ ___ ___ ___ ___ ___ ___ ___

GENERAL QUESTIONS

1. Have you seen any confusion or incorrect operation on the part of other crew members in the use of these 767 systems? If so, what?

   AFDS (MCP) and Autothrottle

   ADI/EHSI

   FMS/CDU

   EICAS

2. Have you ever been "surprised" by the actions of the automatics, that is, they did or did not do something you expected? If so, please explain.

3. Are there any features about the systems below that you are not quite sure about, or that you do not feel comfortable with? Please descibe.

	Feature not sure of	What do you think the problem is?
AFDS (MCP) and Autothrottle		
ADI/EHSI		
FMS/CDU		
EICAS		

4. What feature or capability do you like most and like least about each of the following systems?

	Feature liked the most	Feature liked the least
AFDS (MCP) and Autothrottle		
ADI/EHSI		
FMS/CDU		
EICAS		

5. If you could make any changes in the cockpit (layout, add or delete features, lighting, ventilation, noise, etc.) what would they be?

6. What area(s) should receive more or less emphasis in training? (Consider both ground and simulator.)

ID code ___ ___ ___ ___ ___ ___ ___ ___

767 PILOT QUESTIONNAIRE

The following statements describe reactions to flying, new cockpit technology, and the 767 equipment. For each item, indicate how much you agree or disagree with the statements, as they refer to yourself, by circling the appropriate letter on each scale.

ANSWER QUICKLY: YOUR FIRST IMPRESSION IS THE BEST. Remember to answer every question even if you are unsure.

Feel free to add any comments after you have circled all the answers.

1. I can fly the airplane as smoothly and safely by hand as with automation.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

2. Younger pilots catch on to automation faster than older ones.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

3. Flying today is more challenging than ever.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

4. The FMS/CDU is easy to use in normal line flying.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

5. I think they've gone too far with automation.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

6. Autoland capability definitely enhances safety.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

7. I spend more time setting up and managing the automatics (such as the FMS/CDU) than I would hand flying or using the old style autopilots.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

8. I like to use the new features of the 767 as much as possible.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

9. I am worried about sudden failures of the new devices like the FMS Computer and the CRT displays.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

10. I use automatic devices a lot because I find them useful.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

11. I enjoy flying the 767 more than the older aircraft.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

12. I always know what mode the Autopilot/Flight Director is in.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

13. I can fly as efficiently as the FMS without its help.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

14. I hand fly part of every trip to keep my skills up.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

15. Automation does not reduce workload, since there is more to keep watch over.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

16. I can find the exact location of important controls and switches without any hesitation.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

17. Automation is the thing that is going to turn my company around and make it profitable again.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

18. Pilots who overuse automation will see their flying skills suffer.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

19. The ADI and EHSI displays are always legible and easy to read.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

20. I am favorable toward automation in the cockpit - the more the better.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

21. Flying the 767 is definitely easier than flying other aircraft.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

22. Setting piloting priorities with this new cockpit technology is no more difficult than in our other airplanes.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

23. We should have full autothrottles on all the company's aircraft.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

24. Automation frees me of much of the routine, mechanical parts of flying so I can concentrate more on "managing" the flight.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

25. I have serious concerns about the reliability of this new equipment.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

26. Sometimes what the automatics do or don't do takes me by surprise.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

27. It is easier to cross-check the other pilot in the 767 than in our other airplanes.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

28. Too much automation can be dangerous.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

29. The new equipment is more reliable than the old.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

30. It is important to me to fly the most modern plane in the company's fleet.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

31. I am concerned about a possible loss of my flying skills with too much automation.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

32. Automation reduces overall workload.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

33. I always feel I am ahead of the airplane.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

34. Hand flying is the part of the trip I enjoy most.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

35. I use automatic devices mainly because the company wants me to.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

36. The FMS/CDU requires little or no in-flight button-pushing below FL180.

A	B	C	D	E
strongly agree	slightly agree	neither agree nor disagree	slightly disagree	strongly disagree

Appendix B

Frequency-of-Use Table

The frequency of use table was distributed in two forms (see Appendix A) because of some ambiguities in the instructions and some apparent inconsistencies in the response to the table. The second version of the table attempted to resolve the ambiguities by explicitly showing the four mutually exclusive AFDS modes: CMD (command), CWS (control wheel steering), Hand-fly with FD (Flight Director), and Hand-fly without FD. Both versions had these instructions in common:

> For each phase-of-flight column in the table, enter the percent of your legs on which you use the feature described on the left..."

For both versions, the pilots (correctly) interpreted the instructions in one of two ways. About 75% of the pilots filled in numbers for which the percentages add up to 100 (the 100% group), and the remaining pilots used numbers that added up to more than 100% (the greater-than-100% group). The ambiguity arises because more than one feature can be used during a particular phase of flight. In fact, several pilots reported (in the margins) hand-flying to 10000 ft and then engaging the CMD mode. The 100% group reported this as 25% hand flying, and 75% CMD, whereas the the other group would report this as 100% for each feature in this phase of flight. Because of these different reporting styles, the two groups (the 100% and greater-than-100%) have their use of the autopilot modes reported separately.

The data were reduced to a common format for the autopilot use as follows: for the first version of the table that did not explicitly contain a CMD row, a CMD row was created by adding up the use for the other three modes and subtracting the sum from 100; thus this should be considered a lower bound to the use that would have been reported had the CMD row been in the table.

The results are summarized in Table B. Since percentages are being reported, there is a substantial "floor" and "ceiling" effect, and a traditional measure of means and standard deviations are meaningless. Each cell in the table reports the quartile scores (Q1, Q2, and Q3) and the number of valid responses in each cell; these quartile points divide the valid responses into four equal sized groups; thus, one-quarter of the responses fall below the level in the Q1 row; one-half fall below the level in the Q2 row; and three-quarters of the responses fall below the level in the Q3 row. For example, in the greater-than-100% group, there were 23 valid responses for the "hand-fly with flight director" mode during the "Transition and enroute climb" phase of flight: one-quarter of the responses (about 6) fell below 52.5 %; one-half of the responses (about 12) fell below 90%; and three-quarters of the responses (about 18) fell below 93.75%. Linear interpolation is used on the percent of legs and the number of responses to calculate the quartile points.

Table B. Frequency of Use

FEATURE		PHASE OF FLIGHT: Takeoff to 1000 AGL	Transition & En-route Climb	Cruise	Descent (Cruise to 10,000 MSL)	Terminal Area	Final Approach	Landing
GREATER THAN 100% GROUP								
CMD	Q1	0.0	52.5	100.0	82.5	50.0	25.0	0.0
	Q2	0.0	90.0	100.0	95.0	75.0	50.0	10.0
	Q3	0.0	93.75	100.0	100.0	87.5	50.0	20.0
	N	18	23	23	23	23	23	22
CWS	Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	N	27	29	28	29	29	29	26
HAND FLY:NO FD	Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q2	0.0	2.0	0.0	0.0	17.5	17.5	10.0
	Q3	25.0	50.0	17.5	45.0	40.0	40.0	32.5
	N	25	25	23	24	24	24	20
HAND FLY:FD	Q1	68.75	10.0	0.0	5.0	20.0	50.0	50.0
	Q2	100.0	50.0	2.5	20.0	60.0	75.0	82.5
	Q3	100.0	94.0	80.0	80.0	80.0	88.25	98.0
	N	29	28	26	26	26	25	22
100% GROUP								
CMD	Q1	0.0	20.0	96.5	80.0	50.0	20.0	0.0
	Q2	0.0	55.0	100.0	90.0	67.0	40.0	5.0
	Q3	0.0	90.0	100.0	100.0	82.5	50.0	10.0
	N	53	70	68	67	68	67	65
CWS	Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	N	64	70	70	69	70	70	65
HAND FLY:NO FD	Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q2	0.0	0.0	0.0	0.0	0.0	0.0	5.0
	Q3	10.0	5.0	0.0	0.0	6.25	10.0	45.0
	N	59	56	52	52	53	57	56
HAND FLY:FD	Q1	90.0	15.0	0.0	0.0	15.0	50.0	65.5
	Q2	100.0	50.0	0.0	10.0	30.0	55.0	90.0
	Q3	100.0	80.0	2.75	20.0	50.0	77.5	100.0
	N	68	66	61	61	66	68	64

Table B. Frequency of Use (con)

FEATURE		PHASE OF FLIGHT						
		Takeoff to 1000 AGL	Transition & Enroute Climb	Cruise	Descent (Cruise to 10,000 MSL)	Terminal Area	Final Approach	Landing
VERTICAL SPEED	Q1	0.0	0.0	0.0	22.5	20.0	0.0	0.0
	Q2	0.0	10.0	0.0	50.0	50.0	0.0	0.0
	Q3	0.0	30.0	0.0	85.0	80.0	20.0	0.0
	N	54	89	44	92	89	64	32
BANK LIMIT AUTO	Q1	0.0	50.0	62.5	50.0	23.75	2.5	0.0
	Q2	90.0	90.0	100.0	100.0	75.0	80.0	80.0
	Q3	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	N	77	94	92	94	89	83	57
BANK LIMIT MANUAL	Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q2	0.0	25.0	7.5	10.0	50.0	25.0	10.0
	Q3	50.0	57.5	100.0	56.25	100.0	100.0	95.0
	N	71	87	80	81	89	83	56
LNAV	Q1	0.0	80.0	95.0	90.0	50.0	0.0	0.0
	Q2	0.0	90.0	100.0	95.0	60.0	25.0	0.0
	Q3	0.0	100.0	100.0	100.0	85.0	71.25	50.0
	N	58	100	100	96	96	73	46
VNAV	Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q2	0.0	5.0	10.0	0.0	0.0	0.0	0.0
	Q3	0.0	75.0	95.0	50.0	8.75	0.0	0.0
	N	36	50	43	45	39	35	27
FL CH	Q1	0.0	72.5	0.0	22.5	20.0	0.0	0.0
	Q2	0.0	90.0	10.0	50.0	50.0	0.0	0.0
	Q3	0.0	100.0	100.0	80.0	80.0	20.0	0.0
	N	52	100	41	96	90	50	23
APPROACH MODE	Q1	0.0	0.0	0.0	0.0	0.0	50.0	10.0
	Q2	0.0	0.0	0.0	0.0	22.5	60.0	60.0
	Q3	0.0	0.0	0.0	0.0	50.0	80.0	76.25
	N	15	13	11	12	28	96	57
AUTOLAND	Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.88
	Q2	0.0	0.0	0.0	0.0	0.0	10.0	5.0
	Q3	0.0	0.0	0.0	0.0	0.0	20.0	10.0
	N	15	13	12	13	13	43	89

Table B. Frequency of Use (con)

FEATURE		PHASE OF FLIGHT						
		Takeoff to 1000 AGL	Transition & En-route Climb	Cruise	Descent (Cruise to 10,000 MSL)	Terminal Area	Final Approach	Landing
AUTO-THROTTLE	Q1	90.0	100.0	98.0	70.0	63.0	25.0	0.0
	Q2	100.0	100.0	100.0	90.0	80.0	50.0	7.5
	Q3	100.0	100.0	100.0	100.0	100.0	80.0	40.0
	N	91	92	92	92	92	90	86
MAP MODE	Q1	95.75	95.0	100.0	100.0	90.0	50.0	50.0
	Q2	100.0	100.0	100.0	100.0	100.0	80.0	80.0
	Q3	100.0	100.0	100.0	100.0	100.0	95.0	95.0
	N	99	100	99	99	100	97	86
VOR/ILS	Q1	0.0	0.0	0.0	0.0	0.0	10.0	8.75
	Q2	0.0	0.0	0.0	0.0	5.0	30.0	25.0
	Q3	5.0	10.0	5.0	5.0	20.0	50.0	50.0
	N	68	76	74	75	82	97	85
ALTITUDE (GREEN) ARC	Q1	0.0	10.0	0.0	80.0	10.0	0.0	0.0
	Q2	0.0	80.0	0.0	100.0	80.0	0.0	0.0
	Q3	0.0	100.0	0.0	100.0	100.0	2.0	0.0
	N	43	81	25	99	73	45	29
DIRECT INTERCEPT	Q1	0.0	50.0	33.0	25.0	20.0	0.0	0.0
	Q2	20.0	80.0	77.5	67.5	40.0	0.0	0.0
	Q3	100.0	100.0	100.0	100.0	90.0	50.0	0.0
	N	59	99	94	92	91	55	28
STEP CLIMB	Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q3	0.0	20.0	10.0	0.0	0.0	0.0	0.0
	N	21	38	25	17	16	15	14
FIX MODE	Q1	0.0	0.0	27.5	0.0	0.0	0.0	0.0
	Q2	0.0	10.0	67.5	20.0	0.0	0.0	0.0
	Q3	0.0	25.0	100.0	50.0	10.0	0.0	0.0
	N	40	77	100	83	71	52	33
VOR MANUAL TUNE	Q1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Q2	10.0	5.0	2.0	1.0	10.0	10.0	0.0
	Q3	90.0	15.0	10.0	10.0	25.0	25.0	10.0
	N	82	84	82	81	89	89	55

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16. Abstract
A joint Airline/NASA field study of B-767 training and operations was conducted during the period this aircraft was being introduced into line service. The objectives of the study were: (a) to identify any adverse reactions to the new technology; (b) to provide a "clearing house" of information for the airlines and pilots during the introductory period; (c) to provide feedback on airline training programs for the new aircraft; and (d) to provide field data to NASA and other researchers to help them develop principles of human interaction with automated systems. It is concluded that: (a) a large majority of pilots enjoy flying the B-767 more than the older aircraft; (b) pilots accept new cockpit technology and find it useful; (c) pilots are aware of the potential loss of flying skills because of automation, and take steps to prevent this from happening; (d) autopilot/autothrottle interactions and FMS operations were sometimes confusing or surprising to pilots, and they desired more training in this area; (e) highly automated cockpits can result in a loss of effective monitoring performance; and (f) pilots should be trained to "turn it off" rather than try to "program" their way out of anomalous situations. Human factors principles of cockpit design are discussed.

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